(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
9 January 2003 (09.01.2003)

PCT

(10) International Publication Number
WO 03/003617 A2

(51) International Patent Classification[7]: H04B 7/26, H04J 4/00

(21) International Application Number: PCT/GB02/03009

(22) International Filing Date: 28 June 2002 (28.06.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0116015.9 29 June 2001 (29.06.2001) GB

(71) Applicant (*for all designated States except US*): **SEPURA LIMITED** [GB/GB]; Radio House, St. Andrews Road, Cambridge CB4 1GR (GB).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **BALL, Diana, Margaret** [GB/GB]; 56 Barrons Way, Comberton, Cambridgeshire CB3 7DR (GB). **RAYNE, Mark, Wentworth** [GB/GB]; 5 St. James Close, Stretham, Nr. Ely, Cambridgeshire CB6 2 ND (GB). **WILSON, John, Francis** [GB/GB]; Westcroft Cottage, 206 High Green, Great Shelford, Cambridge CB2 5EG (GB).

(74) Agent: **FRANK B, DEHN & CO.**; 179 Queen Victoria Street, London EC4V 4EL (GB).

(81) Designated States (*national*): AE, AG, AL, AM (utility model), AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ (utility model), DE (utility model), DK (utility model), DM, DZ, EC, EE (utility model), ES, FI (utility model), GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK (utility model), SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declaration under Rule 4.17:
as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for all designations

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: COMMUNICATIONS SYSTEMS

	Slot 1	Slot 2	Slot 3	Slot 4
Carrier 1	a	b	c	d
Carrier 2	a	b	c	d
Carrier 3	a	b	c	c
Carrier 4	a		c	c
Carrier 5	a	d		
Carrier 6	a	d	d	

(57) Abstract: A communications system in which communications stations can transmit and receive more than one carrier frequency simultaneously. Communications channels consisting of simultaneous timeslots on different carrier frequencies are assigned to parties requesting a call depending on the particular data rate requested for the call. The system determines how many timeslots per frame the requested data rate corresponds to and then allocates the appropriate number of timeslots to the channel. Although an integer number of timeslots per frame must be allocated to the channel, the slots may otherwise be allocated in any way desired. Thus, for example, a data rate corresponding to six timeslots per frame could be provided by a channel (channel a) which consists of one slot on each of six different carriers or by a more dispersed allocation of slot 3 on carriers 1 to 4 and slot 4 on carriers 3 and 4 (channel c). A rate of three slots per frame could be provided by a channel (channel b) consisting of slot 2 on carriers 1, 2 and 3. These slot patterns repeat for successive frames.

WO 03/003617 A2

Communications Systems

The present invention relates to communications systems, and in particular to mobile communications systems such as private and public mobile telephony (radio) systems.

Many communications systems, such as GSM (Global System for Mobile Communications) and TETRA (TErrestrial Trunked RAdio), are arranged in a time division multiple access (TDMA) format in which one or more radio frequency carriers are each composed of a number of discrete timeslots, with each timeslot consisting of a (and usually the same) fixed period of time. Generally, in such systems a fixed number of timeslots are grouped together to make a "frame", and the frames repeat regularly in time.

In the operation of such systems, communications channels, each of which may serve a different user or group of users, are created and destroyed as communications requirements change, with each such channel usually being made up of the same particular timeslots in each frame. Thus a single radio frequency carrier will typically be divided up into one or more channels (depending on the number of timeslots in a frame and how those timeslots are allocated to the communication channels). Examples of such communications systems arrangements include GSM (particularly in its GPRS form where multiple timeslot allocations are possible), TETRA and DECT.

In the GSM system, for example, a single timeslot lasts 0.577 ms. The timeslots are arranged in repeating groups of eight timeslots, each group making up a regularly repeating "frame" of length 4.615 ms. (See, for example, M. Mouly and M. Pautet, "The GSM System For Mobile Communications", 1992, ISBN 2-9507190-0-7, Cell

and Sys, 4 Rue Elisée Reclus, F-91120, PALAISEAU, FRANCE).

In TETRA, each timeslot lasts 14.167 ms, and there are 4 timeslots in a repeating frame of length 56.67 ms. 18 such frames constitute a multi-frame, and 60 multi-frames constitute a hyper-frame. A transmitting mobile station may transmit on one to four timeslots per frame, and a base station usually transmits on all four timeslots per frame (to the same or differing mobile stations). On some occasions (e.g. for random access signalling), a mobile station may transmit short bursts within the first or second half of a timeslot. It is possible to allocate from 1 to 4 timeslots per frame to a single TETRA communications channel to provide different data transmission rate channels. (See for example, "Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D); Part 2: Air Interface (AI)", EN 300 392-2, available from ETSI, F06921 Sophia Antipolis CEDEX - FRANCE).

In such arrangements, the data rate of a communications channel will depend on the number of timeslots allocated to the channel. If each timeslot accommodates n bits of signalling or user data and lasts t seconds, the data rate per timeslot is n/t bits per second per timeslot. A channel possessing C timeslots per frame will therefore have a data rate of r = Cn/t bits per second.

New developments in signal processing now make it possible to increase the number of bits of information that can be transmitted in a given time period, for example by increasing the modulation rate or level of the signalling, or by increasing the band width of the transmission (e.g. by transmitting on more carrier frequencies simultaneously), or both.

It is becoming increasingly desirable to enhance existing communications systems in this manner. However, the Applicants have recognised that when this

is done, it would be desirable to maintain backward compatibility with the original transmission format and protocol, and to, for example, use the existing transmission burst structure and protocol methods with the enhanced data rate.

For example, where data is transmitted simultaneously on multiple radio frequency carriers which are combined in some way to provide a new, higher capacity communications channel, to provide consistency and compatibility for older communications systems, it would be desirable to preserve the original structure of the time division multiple access (TDMA) timeslots and frames. This is because, for example, the existing transmission protocol may expect to see a consistent transmission block length structure in a communications channel, and this should desirably be preserved when constructing larger capacity, multi-carrier communications channels.

According to a first aspect of the present invention, there is provided a method of operating a time division multiple access communications system in which plural individual carriers are divided into regularly repeating frames each comprising a predetermined number of timeslots, the method comprising:

allocating for use as a communications channel, timeslots on more than one carrier frequency in each transmission frame, and wherein the allocated timeslot pattern repeats for selected succeeding transmission frames.

According to a second aspect of the present invention, there is provided an apparatus for use in a time division multiple access communications system in which plural individual carriers are divided into regularly repeating frames each containing the same number of timeslots, the apparatus comprising:

means for allocating for use as a communications

channel a pattern of timeslots on more than one carrier frequency in a single transmission frame which repeats for selected succeeding transmission frames.

In the present invention, timeslots on different radio frequency carriers are allocated into a single communications channel, thereby providing a higher data rate channel. Furthermore, the same, fixed pattern of timeslots is used for selected successive frames. In other words, communications channels are created by assigning frame-sized patterns of timeslots across multiple carriers. This provides a convenient timeslot structure for the enhanced data rate capacity channel that is in particular compatible with the existing transmission structure, format and protocol, etc., of the communications system.

The timeslot pattern preferably repeats for each successive transmission frame until the channel is no longer needed. Thus, there is preferably a run of contiguous, immediately successive frames in which the timeslot pattern for the channel is repeated. However, it would also be possible to transmit the channel (and therefore repeat its timeslot pattern) in only, say, every other frame, or every fourth frame, etc., i.e. not in every immediately successive frame. This could give greater channel allocation flexibility.

The allocation of timeslots to a channel can be carried out as desired, and is preferably fully flexible as far as possible within a single frame, e.g. such that timeslots can effectively be allocated to a channel at random within a single frame. It is in particular preferred to be able to use single, isolated timeslots on a carrier in any communications channel. Thus, preferably, a channel can be allocated any unused timeslots in a frame in any pattern or combination whatsoever. Having a more flexible timeslot allocation process helps to facilitate the maximum possible utilization of bandwidth when providing multiple

separate channels (unlike, for example, where timeslot allocations have to take place in blocks of fixed dimensions), since it permits the available radio carrier frequencies to be fully utilised.

Thus, it is preferred for there to be no restrictions on the possible slot allocations. In particular, there is preferably no requirement to use particular (e.g. predetermined) timeslot patterns, and/or to use a fixed number of timeslots per carrier. Thus, for example, a given channel can preferably include a different number of timeslots on each different carrier frequency making up the channel. Similarly, while the channel may include simultaneous timeslots on more than one different carrier, this is not mandatory, and the different carriers of the channel could each use different timeslots in the frame. By avoiding such timeslot allocation restrictions, the possibility of using isolated timeslots is enhanced, as is the efficient use of the available carrier spectrum.

In a preferred embodiment, the timeslot allocation is, as far as possible, symmetrical and/or is such that (adjacent) timeslots on a given carrier frequency are at regular (preferably equal) intervals (i.e. the spacings between (adjacent) timeslots are regular (and preferably equal). Thus, for example, in such an arrangement in the TETRA system, the channel would be allocated slots 1 and 3 or slots 2 and 4 on a carrier frequency of the channel (and preferably on all carrier frequencies for the channel) in each TETRA frame of the channel. The Applicants have found that using such a more "balanced" timeslot allocation can help to avoid unwanted frequency peaks in the transmitted signal.

Thus according to a third aspect of the present invention, there is provided a method of operating a time division multiple access communications system in which plural individual carriers are divided into regularly repeating frames each comprising a

predetermined number of timeslots, the method comprising:

allocating for use as a communications channel a pattern of timeslots on more than one carrier frequency in a single transmission frame which repeats for selected succeeding transmission frames, and in which pattern adjacent timeslots on a carrier frequency of the channel are at regular intervals.

According to a fourth aspect of the present invention, there is provided an apparatus for use in a time division multiple access communications system in which plural individual carriers are divided into regularly repeating frames each containing the same number of timeslots, the apparatus comprising:

means for allocating for use as a communications channel a pattern of timeslots on more than one carrier frequency in a single transmission frame which repeats for selected succeeding transmission frames and in which adjacent timeslots on a carrier frequency of the channel are at regular intervals.

Preferably the timeslot allocation is such that adjacent timeslots on each carrier frequency used for the channel are at regular (and preferably identical) intervals (i.e. have regular, preferably identical spacings).

There will be, as will be appreciated by those skilled in the art, some inevitable restrictions on timeslot allocation, such as the constraints of the frame size and number of available carriers, and any pre-existing timeslot allocations that may be in place at the time (i.e. such that some timeslots are not available for the channel as they are already in use).

Furthermore, it is preferred for the timeslot allocation to be based (as far as possible) on certain defined criteria. For example, the timeslot allocation is preferably based on the desired data rate for the channel, e.g. by computing how many timeslots per frame

the desired data rate corresponds to (using, e.g. C = rnt, as discussed above).

Similarly, where certain users of the communications system, such as mobile stations, have a limited RF bandwidth (i.e. they can only receive a certain range of carrier frequencies), the timeslot assignment for channels to be used by such users is preferably appropriately restricted to carrier frequencies that the user can use.

Where the communications system supports plural different modulation schemes (rates and/or levels), it is preferably possible for these modulation schemes to be available for the multi-carrier channel. The ability to use different modulation schemes further enhances the flexibility of the channel allocation arrangement and the efficient use of frequency spectrum bandwidth.

In such an arrangement, the system preferably selects which modulation scheme to use for a given channel in accordance with one or more selected, preferably predefined, criteria. For example, where the different modulation schemes provide different data capacities per timeslot, the modulation scheme used could be selected based on the desired data rate for the channel and/or the number of available timeslots. It is also the case that at higher modulation levels (for a given transmitter power), the energy per bit and hence transmission range is reduced. Thus the signal level and/or bit error rate could also be taken into account when selecting which modulation scheme to use.

The interleaving scheme used for the multi-carrier channel can be selected as desired, and preferably plural interleaving depths are available for each multi-carrier channel.

In a particularly preferred embodiment, where interleaving is to be used for a multi-carrier channel, that interleaving does not take place across the carrier frequencies (i.e. the interleaving is carried out

independently on each carrier frequency). This is because interleaving data bits across frequencies requires the interleaving scheme to vary according to the number of frequencies in use, which would make it difficult to vary the number of frequencies used in a channel (since the interleaving scheme would have to vary as the number of frequencies is varied, thereby leading to variable performance and protocol complexities).

According to a fifth aspect of the present invention, there is provided a method of interleaving data to be transmitted on a communications channel comprising plural different carrier frequencies, the method comprising:

interleaving the data on each carrier frequency of the channel separately to the data on the other carrier frequencies of the channel.

According to a sixth aspect of the present invention, there is provided an apparatus for interleaving data to be transmitted on a communications channel comprising plural different carrier frequencies, the apparatus comprising:

means for interleaving the data on each carrier frequency of the channel separately to the data on the other carrier frequencies of the channel.

Preferably, carrier frequencies can be added to or removed from a channel as desired, and there is no need for there to be a fixed number of frequencies in use. This again enhances the flexibility (and thus potential efficiency) of the timeslot allocation process.

In a particularly preferred embodiment, the timeslot pattern, modulation scheme, or both, etc., allocated to a communications channel may be modified while the channel is in use. This could be done, for example, if the channel quality changes, or if higher priority users request channels, or if the users of the channel themselves request a different number of

timeslots or data rate per frame.

Preferably, plural simultaneous multi-carrier channels in accordance with the present invention can be assigned (e.g. to different users). This could be done, for example, using different interlocking timeslot patterns. Preferably the timeslots allocated to each channel can be picked from any unused timeslots, i.e. the different channels can be allocated timeslots from all available timeslots. When a channel becomes disused, its timeslots can be assigned to one or more new channels, as required. There is preferably a selected group or pool of carriers which can be used to make up the multi-carrier channels (with each channel then using different timeslots of the carriers).

Where different modulation schemes are supported by the communications system, it would be possible to assign different modulation schemes to different multi-carrier channels, although each timeslot allocated to a particular channel preferably uses the same modulation scheme (as that will simplify higher-layer protocol considerations, which could otherwise be very complex). This type of arrangement would require the appropriate communications station's, e.g. base station's transmitter and receiver to be capable of switching their modulation level and/or type in between timeslots. This could be assisted by, for example, the transmitter introducing special phasing bits to avoid large phase discontinuities and consequent spurious emissions at the change-over point, or by the transmitter in a controlled fashion switching off the RF carrier between slots, changing the modulation type and switching the carrier on again.

It would also be possible to assign different interleaving depths to different channels, e.g. different multi-carrier channels. In such an arrangement, it is again preferred for the timeslots allocated to a particular channel to use the same

interleaving depth (to simplify higher-layer protocol considerations which could otherwise be very complex, and to provide a constant time delay).

Thus where plural channels exist in a frame, it is preferred that individual channels can use different modulation rates, channel coding and/or interleaving methods (where appropriate).

While it would be possible to have selected radio frequency carriers permanently dedicated to multiple carrier channel use, in a particularly preferred embodiment, the radio frequency carriers can (selectively) be used for different purposes, such as for a multiple carrier channel in accordance with the present invention, a standard voice call, etc., with the purpose of an individual carrier being assigned appropriately. Preferably the use of the carriers can be altered dynamically in use, so that, for example, at some times they may be dedicated to voice calls and at others to multi-carrier channel use. There could, for example, be a dynamically variable pool of carriers reserved for multi-carrier channel use, with the number of carriers in the pool varying according to, for example, current communications system usage. For example, where a large number of voice calls is required (e.g. as might be the case in public safety operations at peak times or in an emergency event) some or all (or as many as required) of the carriers used for multi-carrier channels could be reassigned to voice call usage.

It would also be possible for a carrier to be used simultaneously for both a multi-carrier channel and some other purpose, such as a voice call. In such a case, one or more timeslots on the carrier could be used for a multi-carrier channel, and other, previously free, timeslots, used for a voice call.

Where a given carrier carries both a multi-carrier channel and a voice call, for example, it is not

necessary for the multi-carrier channel and the voice call to use the same modulation type and/or level, although, as discussed above, to be able to do this, the appropriate communications stations, such as base stations, will need to be able to switch between modulation types at timeslot boundaries.

The carrier frequencies allocated to a given multi-carrier channel can be selected as desired (subject to the frequencies available to the communications system). However, in a particularly preferred embodiment, a given channel is made up of carrier frequencies that are close to each other (e.g. within a certain, preferably predetermined, frequency bandwidth). Most preferably, the channel is made up of adjacent carriers as far as possible, and preferably of adjacent carriers only (whenever that is possible). (As is known in the art, communications systems typically arrange their carrier frequencies at fixed frequency spacings (usually 25 kHz in TETRA) across the available frequency spectrum).

It is similarly preferred that the group or pool of carriers available for use for the multi-carrier channels extend over a narrow bandwidth and most preferably comprise a, preferably contiguous, block of adjacent carriers.

Using closely spaced and adjacent carriers for a multi-carrier channel can help to simplify receiver design. This is because a receiver must be capable of receiving data on all the carriers on which it is being sent. However, where carriers are spaced further apart, it can be difficult and costly (particularly in the mobile station) to design a single receiver that can receive and demodulate all the carriers simultaneously. This could be achieved by using more than one receiver, but that may be undesirable on grounds of equipment size, cost and power consumption. However, it is possible to design a cost effective single receiver that

can receive multiple carriers simultaneously, if the carrier frequencies are adjacent (or at least very close). The degree of difficulty of implementing such a receiver depends strongly on the bandwidth of the group of carriers forming the channel, and hence the use of adjacent carrier frequencies is preferred.

The use of adjacent carriers can also have a beneficial effect on the spectral efficiency of a communications system. For example, the adjacent carrier spurious power levels of a number of communications systems (such as GSM) are quite high, which can mean that two neighbouring cells cannot use adjacent carriers due to the unacceptably high levels of interference that might result. In a site with n carriers spaced some distance apart, there are 2n adjacent channels. However, with the carriers in contiguous block, there are only two adjacent channels, and thus there are many more interference-free carriers in the system, thereby making frequency planning easier and spectral efficiency higher.

Thus, according to a seventh aspect of the present invention, there is provided a method of allocating radio frequency carriers in a communications system to a communications channel that uses plural radio frequency carriers, the method comprising:

allocating as far as possible adjacent frequency carriers to the channel.

According to an eighth aspect of the present invention, there is provided an apparatus for allocating radio frequency carriers in a communications system to a communications channel that uses plural radio frequency carriers, the apparatus comprising:

means for allocating as far as possible adjacent frequency carriers to the channel.

According to a ninth aspect of the present invention, there is provided a communications system in which multiple-carrier frequency channels can be

provided, wherein the carrier frequencies available for use in multi-carrier channels comprise a contiguous block of adjacent carrier frequencies.

One potential problem with using a limited pool of adjacent carriers for the multi-carrier channels is that that could lead to interference problems, in particular so-called "near-far effect" interference problems when a receiver has to receive two such channels simultaneously (e.g. such as might be the case for base station receivers on the uplink (the communications link between the mobile transmitters and the base station receivers)). This interference arises where a (e.g. mobile) station which is close to a receiving (e.g. base) station (thereby presenting it with a strong signal), causes interference to the receiver on one of the other carriers used in the system on which the receiver is receiving a weak signal from another more distant station. This type of interference is usually caused either by spurious power transmitted by the closer station on either side of its wanted transmission frequency, and/or by inadequacies in the receiver (usually termed blocking). This problem increases as the frequency spacing between the carriers decreases (and can therefore be avoided by allocating carriers with considerable frequency spacing between them (but as noted above this may not be desirable)).

Thus when using adjacent carriers for the multi-carrier communications channel and a narrower bandwidth pool of frequencies, the timeslot and carrier channel allocation process preferably takes account of possible near-far effect interference problems.

In a particularly preferred such embodiment, the channel allocation (both in terms of timeslots and carriers) is based on a signal strength indication (e.g. the actual received signal strength, or preferably an average thereof, e.g. over a few seconds (to increase the accuracy of the measurement)) for the received

signal (e.g. uplink signal) and/or for the other signals currently being received.

Thus according to a tenth aspect of the present invention, there is provided a method of allocating timeslots and carrier frequencies to a communications channel in a communications system in which channels comprising multiple carriers are possible, comprising:

allocating timeslots and/or carriers to the channel on the basis of an indication of the signal strength of a signal that is to use the channel and/or on the basis of an indication of the signal strength of a signal that is using an existing channel of the communications system.

According to an eleventh aspect of the present invention, there is provided an apparatus for allocating timeslots and carrier frequencies to a communications channel in a communications system in which channels comprising multiple carriers are possible, comprising:

means for allocating timeslots and/or carriers to the channel on the basis of an indication of the signal strength of a signal that is to use the channel and/or on the basis of an indication of the signal strength of a signal that is using an existing channel of the communications system.

Preferably in these arrangements, where there is a strong signal (e.g. above a particular, predetermined indicated signal strength) in particular timeslots, any new channels, particularly having weak signals, are allocated in timeslots that the strong signal does not exist in (does not overlap with in time), i.e. in timeslots that are not simultaneous with the timeslots of the strong signal. This allows any interference from the strong signal to be avoided, as the interference protection between time-spaced timeslots is infinite.

Where simultaneous timeslots have to be used (and otherwise), it is then preferred to place other channels on carriers that are spaced as far in frequency as

possible (given the available frequency range and available carriers within the range) from the strong signal, as that should again reduce the interference effects (by virtue of the signals being spaced in frequency).

Furthermore, where it is known that a call or requested channel will have a strong signal (high signal strength, e.g. above some predetermined value), it is preferred to allocate such a call a channel in such a way that the call uses the minimum number of timeslots and/or takes the least time to complete (as that again will help to ensure that a minimum of interference is caused). This can be achieved, for example, by using the highest possible data rate for the call (e.g. by using the highest available modulation level), which can, for example, either reduce the time for the call (e.g. data transfer), or the number of timeslots used for the call per frame.

It is also preferred, particularly for strong signals, to maximise as far as possible the number of simultaneous timeslots used for the channel for that signal (e.g. by using the same timeslot in parallel across as many available carriers as possible), rather than timeslots in series on a single carrier, as that can again avoid a strong signal appearing across plural timeslots of a frame and help the call to be processed quicker.

In another preferred embodiment, the system can additionally or alternatively alter existing channel allocations to enable a new channel to be assigned timeslots where the possibility of interference is reduced.

These preferred slot and carrier allocation schemes on the basis of signal strength indication thus help to facilitate the use of adjacent carriers for different channels, whilst reducing or avoiding near-far interference problems. These techniques are therefore

particularly useful where there is a limited pool or range of carriers to choose from when allocating plural simultaneous multi-carrier channels, as they help to allow adjacent channels to be used without interference effects.

In another particularly preferred embodiment, power control techniques are used to try to ensure that the signals from all transmitters (e.g. mobile stations) arrive at the receiver, e.g. base station, at the same power level (as that would avoid the problem of strong and weak signals interfering (and therefore reduce the need to allocate timeslots as discussed above to try to avoid interference)).

(As is known in the art, many mobile communications systems support the use of power control for, e.g., mobile stations' transmissions to, for example, reduce the amount of interference to other cells of the system using the same or adjacent frequencies. Such power control is typically carried out in one of two ways. The first such way, often referred to as "open loop" power control, involves, as is known in the art, a mobile station measuring the signal strength received from the base station and using that measurement together with, e.g., offsets and limits based on the required signal level at the base station and the difference in the output of its transmitter compared to the base station, to determine the power output to use for its transmitter. The other technique, usually known as "closed loop" power control (e.g. in TETRA) involves the base station measuring the received signal strength from the mobile station and then instructing the mobile station to change its power in order to bring it in line with the desired received signal strength. It is often preferred (and is in the present invention) to use closed loop power control, as that is a generally more accurate technique.)

While power control can be used to help reduce

interference effects, in practice power control may have its limitations in, for example, accuracy. It may also be the case that notwithstanding the use of power control, a mobile station may be unable to turn its power down far enough to avoid e.g. near-far interference effects (e.g. because of the minimum power level of the mobile transmitter - for example, a one Watt TETRA handheld transceiver has a minimum power level of 15 dBm, only 15 dB below its maximum power output). Thus, even where power control is being used, it is still preferred to also allocate timeslots and carriers to channels in accordance with the criteria set out above, e.g. on the basis of some form of signal strength indication.

Where power control is being used, it may be preferable to base the timeslot and carrier allocation on the basis of some form of signal strength indication other than the actual received signal strength. For example, it may be preferable to do it on the basis of what the signal strength would be if power control was not being applied, and/or, for example where this information may not be fully available, on the basis of the (preferably averaged) signal level at call setup or on a random access channel (particularly if power control is not used for random access), or the level of power control being used (e.g. how much power control the system is asking the mobile station to use), as well as or instead of on the (preferably averaged) actual received signal level.

A further consideration with the ability of power control to reduce interference effects relates to its use or otherwise in call setup procedure and random access attempts. If power control is not used for random access attempts, then a wide range of signal levels could be received for such attempts. Thus, where random access and call setup attempts are made on a selected control channel frequency (carrier), as is

usually the case, it is preferred for the control channel (or channels) carrier(s) to be spaced in frequency from the main contiguous group or pool of carriers used for main channel allocation, or at least to be placed on a carrier at the edge of the adjacent contiguous frequency (carrier) group, so that the control channel is less likely to be a source of interference.

The above channel allocation criteria can also be used for downlink channel allocations, and this is in particular preferably done where downlink power control is being used (as downlink power control can cause interference problems at the mobile receiver).

In a particularly preferred embodiment of the present invention, a user, e.g. mobile station or other party, requesting a channel or call or communication includes in their request information about the type of communication (channel) desired. The system should then respond appropriately and as far as possible, and may grant, for example, a multi-carrier channel in accordance with the present invention, or a normal single carrier channel, etc., depending on, for example, system resources and the channel requested. The information in the request could be, for example, an indication of the number of timeslots required for the channel. It should be noted that the system is not obliged to offer the channel requested (e.g. in terms of its data capacity) and could, for example, if resources are limited, offer a different channel or no channel at all.

In a particularly preferred embodiment, the channel or communication request includes an indication of the data rate or capacity desired for the communication (channel). This may be particularly useful where different modulation schemes can be used, such that timeslots can have different data capacities. The indication could be in terms of absolute units of data

rate (e.g. C = rnt as discussed above), but preferably is given in terms of a number of standard data capacity timeslots which can then be converted appropriately to equivalent numbers of timeslots for the various modulation schemes available. The standard data capacity timeslot used for this purpose is preferably a timeslot using one of the modulation schemes available to the system. It is preferably the lowest data capacity modulation scheme, as then timeslots can be requested in integer values.

Thus, according to a twelfth aspect of the present invention, there is provided a method of operating a communications system in which communications channels comprised of plural different carrier frequencies can be used, the method comprising:

a station of the communications system transmitting a request for a communications channel, and including in its request an indication of the data transmission rate or capacity required for the communications channel; and

the system in response to such a request allocating a communications channel comprised of timeslots on plural different carriers, wherein the timeslots allocated to the channel are based on the indicated data transmission rate or capacity.

According to a thirteenth aspect of the present invention, there is provided a communications system in which communications channels comprised of plural different carrier frequencies can be used, the system comprising:

a communications station comprising means for transmitting a request for a communications channel, and including in its request an indication of the data transmission rate or capacity required for the communications channel; and

the system further comprising means for, in response to such a request, allocating a communications channel comprised of timeslots on plural different

carriers, wherein the timeslots allocated to the channel are based on the indicated data transmission rate or capacity.

According to a fourteenth aspect of the present invention, there is provided a communications station of a communications system in which communications channels comprised of plural different carrier frequencies can be used, the communications station comprising:

means for transmitting a request for a communications channel, and including in its request an indication of the data transmission rate required for the communications channel.

According to a fifteenth aspect of the present invention, there is provided a communications station of a communications system in which communications channels comprised of plural different carrier frequencies can be used, the communications station comprising:

means for receiving a request for a communications channel which includes an indication of the data transmission rate required for the communications channel; and

means for, in response to such a request, allocating a communications channel comprised of timeslots on plural different carriers, wherein the timeslots allocated to the channel are based on the indicated data transmission rate or capacity.

The data to be transmitted can be loaded into the timeslots allocated to the communications channel as desired. However, in a particularly preferred embodiment, the data to be transmitted is placed in the timeslots of a given multi-carrier channel according to a predetermined ordering scheme. This helps to allow a receiver to reassemble the data in the same order as it was transmitted. While any suitable ordering scheme would be possible, so long as it is known to both the transmitter and the receiver, in a preferred such scheme, the loading of the timeslots is ordered firstly

by timeslot (i.e. filling up the earliest timeslots in the frame first and so on, with the last timeslots being filled last), and preferably then by carrier number (preferably counting from the lowest frequency carrier to the highest, or vice-versa). Ordering by timeslot first ensures that data which is closely related is transmitted more closely in time, thereby, for example, reducing the delay time to request a retransmission of faulty timeslots.

Thus, according to a further aspect of the present invention, there is provided a method of transmitting data on a communications channel which uses timeslots on plural carrier frequencies, comprising:

allocating the data to the timeslots of the channel for transmission in accordance with a predetermined ordering scheme.

According to another aspect of the present invention, there is provided an apparatus for transmitting data on a communications channel which uses timeslots on plural carrier frequencies, comprising:

means for allocating the data to the timeslots of the channel for transmission in accordance with a predetermined ordering scheme.

It will be appreciated by those skilled in the art that the channel allocation, etc., techniques of the present invention can, and preferably are, used for both uplink and downlink channels. It is also preferred that such arrangements can be asymmetric as between uplink and downlink pairs, e.g. as regards carrier allocations and modulation schemes. This could result in different (independent) uplink and downlink slot assignment patterns. Thus, according to another aspect of the present invention, there is provided a method of operating a communications system, comprising allocating an associated uplink and downlink communications channel pair to users of the system, wherein the timeslot pattern allocated to the uplink channel is different to

the timeslot pattern allocated to the downlink channel.

While the present invention is applicable to communications systems and particularly mobile communications systems, generally, it is particularly applicable to the TETRA mobile communications system. Thus the present invention also extends to a TETRA system incorporating any or all aspects and features of the present invention.

The methods in accordance with the present invention may be implemented at least partially using software e.g. computer programs. It will thus be seen that when viewed from further aspects the present invention provides computer software specifically adapted to carry out the methods hereinabove described when installed on data processing means, and a computer program element comprising computer software code portions for performing the methods hereinabove described when the program element is run on data processing means. The invention also extends to a computer software carrier comprising such software which when used to operate a communications system or station comprising data processing means causes in conjunction with said data processing means said system or station to carry out the steps of the method of the present invention. Such a computer software carrier could be a physical storage medium such as a ROM chip, CD ROM or disk, or could be a signal such as an electronic signal over wires, an optical signal or a radio signal such as to a satellite or the like.

It will further be appreciated that not all steps of the method of the invention need be carried out by computer software and thus from a further broad aspect the present invention provides computer software and such software installed on a computer software carrier for carrying out at least one of the steps of the methods set out hereinabove.

A number of preferred embodiments of the present

invention will now be described by way of example only and with reference to the accompanying drawings, in which:

Figure 1 shows an example of timeslots on a single radio frequency carrier;

Figure 2 shows an example of six radio frequency carriers;

Figure 3 shows examples of multi-carrier channel timeslot allocations in accordance with the present invention for the radio frequency carriers of Figure 2;

Figures 4 to 10 show examples of signalling messages that can be used in a TETRA communications system that can operate in accordance with the present invention; and

Figures 11 and 12 illustrate further timeslot allocation arrangements.

Figure 1 shows an example of timeslots in a TDMA communications system on a single radio frequency carrier 10. The carrier is arranged in regularly repeating frames 11 (frame 1), 12 (frame 2), 13 (frame 3), etc., with each frame comprising four timeslots. In the example shown in Figure 1 the single radio carrier is divided into different channels, each of which may serve a different user or group of users. A first channel 14 uses timeslot 1 of each frame, a second channel 16 uses timeslot 4 of each frame and a third channel 15 uses timeslot 2 and 3 of each frame. Since the third channel has twice the number of timeslots per frame as the other two channels, it offers users twice the data rate. As users come and go, the channels shown in Figure 1 can be destroyed and new channel arrangements created.

In this arrangement, the data rate of a given communications channel depends on the number of timeslots allocated to the channel. If each timeslot accommodates n bits of signalling or user information and lasts t seconds, the data rate per timeslot is n/t

bits per second per slot. If a channel possesses C timeslots per frame, the data rate is therefore r = Cn/t bits per second.

As discussed above, as a result of new processing capabilities it is now becoming possible for a radio transceiver to transmit on multiple radio carriers simultaneously and to receive on multiple radio carriers simultaneously. It is also possible to use higher levels of modulation (which increase the number of information bits that may be transmitted in a single modulation symbol). Both of these techniques can be combined to increase the data capacity of radio channels.

Figure 2 shows a first preferred embodiment of a method of providing higher data rate (capacity) channels in which timeslots on multiple individual radio frequency carriers are allocated into a single communications channel.

Figure 2 shows six radio frequency carriers 21 to 26, each being transmitted in the same TDMA frame structure 27, 28, 29 as shown in Figure 1. The frames and timeslots of each carrier frequency shown in Figure 2 are aligned in time and synchronised. This is a typical arrangement for a TETRA or GSM system. In the normal course in such systems each transmitter or receiver would be able to transmit or receive a single carrier and thus a base station would require six transmitters and receivers for the six radio frequency carriers shown in Figure 2, and a mobile station would transmit or receive one or more timeslots per frame on one of the carriers, or, if in a duplex call, transmit timeslots on one carrier and receive timeslots on a different carrier.

However, as discussed above, it is now possible for a mobile station to be given the ability to transmit and/or receive more than one (perhaps up to six) carrier frequencies simultaneously. In such a case, it would be

possible to allocate a communications channel consisting of simultaneous timeslots on different carrier frequencies.

An example of the allocation of timeslots on multiple individual radio carriers into a single channel will now be described. In this embodiment it is assumed that a mobile station or other party requesting a call requests a particular data rate. The radio system will then compute how many timeslots per frame this corresponds to by using C = rnt. The radio system controller will then allocate the appropriate number of timeslots to the channel. Although an integer number of timeslots per frame must be allocated to the channel, the slots may otherwise be allocated in any way desired. In particular, it is not necessary to allocate channels in particular slot patterns, such as in a fixed number of slots per carrier. By avoiding such restrictions on the slot allocation, the possibility of using isolated slots is enhanced and the maximum possible use of available radio spectrum in a scenario where multiple TDMA carriers are allocated to logical channels is facilitated.

Figure 3 gives some examples of suitable channel timeslot allocations. Assuming, for example, that a data rate corresponding to six timeslots per frame (which could, for example, be required for a particular type of data transaction) has been requested by a mobile station (or by some other end user outside the radio network, such as a call despatcher or a fixed data terminal) then channel a which consists of one slot on each of carriers one to six, providing a data rate of six slots per frame, could be used. On the other hand, channel b in Figure 3 provides a rate of three slots per frame, consisting of slot 2 on carriers 1, 2 and 3. Channel c is a more dispersed allocation providing a data rate of six slots per frame, these being slot 3 on carriers 1 to 4 and slot 4 on carriers 3 and 4. Channel

d in Figure 3 consists of slot 2 on carriers 5 and 6, slot 3 on carrier 6 and slot 4 on carriers 1 and 2. These slot patterns repeat for successive frames.

As can be seen from the examples given in Figure 3, in the present invention the slot allocations can be very dispersed. This could be for many reasons, such as historical slot availability. For example, if in the example shown in Figure 3 a new channel e was required, a four-slot allocation could be provided from carrier 4 slot 2, carrier 3 slots 3 and 4 and carrier 6 slot 4.

Although the embodiments shown in Figures 2 and 3 use only six carriers and have four timeslots per frame, the embodiment (and the present invention) can, as will be appreciated by those skilled in the art, be extended to any number of timeslots and carriers. In particular, even though individual communication stations (e.g. mobile stations) may have a limited RF bandwidth (for example six carriers wide), other communications stations such as base stations may be able to handle a much wider spread of carriers. In such a situation, the radio system (base station) should take account of the bandwidth of individual mobile stations and restrict their timeslot assignments appropriately. Thus, for example, in the examples shown in Figure 3, one of the channels could be restricted to an RF bandwidth or multi-carrier capability of only four carriers if that is all that a mobile station using the channel can handle. However, that would not prevent the radio system from assigning slots to some other channel from a block of four carriers in a different part of the radio spectrum.

While it would be possible to have a dedicated group or pool of carriers for use in the multi-carrier data communications channels of the present embodiment, preferably the use of carriers for this purpose can be altered dynamically, such that at some times the carriers may be used for other purposes, such as voice

calls, and at other times, would be used for multi-carrier data channels. For example, a carrier might at some time be removed from the pool of available multi-carrier data channels (which may mean that all data channel allocations have to be re-assigned to use available timeslots on the remaining carriers (or dropped)), and might later be returned. This could be particularly useful in a communications system used for public safety operations. For example, at peak times, or if some emergency has occurred requiring provision of a large number of voice calls, some or all (or as many as required) of the carriers being used for multi-carrier data communications could be re-assigned by the system for use for the emergency voice calls.

It should be noted that in such arrangement it may not be necessary to completely remove a carrier from multi-carrier use in the event that additional capacity of voice calls is required, but rather one or more spare timeslots on a given carrier may be used for a voice call while other timeslots are still used for a multi-carrier channel. Thus, for example, with reference to Figure 3, slot 2 of carrier 4 is unused and so may be allocated to a voice call of single slot capacity, while the remaining slots on carrier 4 are still used for multi-carrier channels.

Where a carrier is used for both a multi-carrier data channel and a voice call, it would be possible for the modulation level or type for the voice call to differ from the modulation being used for the multi-carrier channel. For this to be possible the base station transmitter must be capable of switching its modulation level or type in between timeslots, and for the base station receiver to be able to switch between modulation levels or type in the same way. This could be further facilitated by, for example, the base station transmitter introducing special phasing bits to avoid large phase discontinuities and consequent spurious

emissions at the change-over point, or alternatively, the transmitter could (in a controlled fashion) switch off the RF carrier between slots, change the modulation type, and switch the carrier on again.

It is also possible for simultaneous multi-carrier data channels to be assigned different modulation types and/or levels. Thus, for example, in Figure 3 channel a might use standard TETRA $\pi/4$ DQPSK, channel b might use 16-QAM, channel c might use 32-QAM and channel d might use 64-QAM. Again, to do this it is necessary for the base station to be able to switch between modulation types at timeslot boundaries. In such arrangements, each timeslot allocated to a particular multi-carrier channel preferably uses the same modulation type, as that will simplify higher-layer protocol considerations, but timeslots allocated to different multi-carrier channels can use different modulation types.

Where different modulation schemes are permitted, the modulation scheme to be used should be chosen appropriately, for example based on the required data transmission rate for the channels. It is also the case that the energy per bit, and therefore the range, is reduced at higher modulation levels. Therefore the radio system (base station) preferably measures the signal level or bit error rate when the data connection is requested, and from time-to-time thereafter, and uses that information to help it choose the most appropriate modulation scheme.

It would also be possible to assign different interleaving depths to different channels (both multi-carrier data channels and voice channels, etc.). In such a case, each timeslot allocated to a particular channel preferably uses the same interleaving depth (to simplify higher-layer protocol considerations, which would otherwise be very complex, and to provide a constant time delay), but timeslots allocated to different channels could use different interleaving

depths. For example, considering the channels shown in Figure 3, channel a could use one-slot interleaving, channel b could interleave across four frames, and channels c and d could interleave across eight frames (which would mean, for example, that for channel c, timeslot 3 on carrier 4, for example, would be interleaved with timeslot 3, carrier 4 of the next eight frames).

While the carrier frequencies made available for multi-carrier channels and allocated to a given multi-carrier channel in the present embodiment can be allocated as desired, and in particular do not need to be adjacent or contiguous, as discussed above it is preferred to use adjacent carriers as far as possible, as a receiver of the multi-carrier channel will require an intermediate frequency bandwidth that is wide enough to receive all of the group of carriers and this is more straightforward when the carriers are close together. Thus, using adjacent carriers is therefore much more cost-effective than when the carriers are spaced further apart.

However, as discussed above, the use of adjacent carriers can lead to problems with near-far interference effects. This will be illustrated with reference to Figure 11. The situation on the uplink in Figure 11 where channel A is in use using slots 1 and 2 of carrier 1 will be considered. It will be assumed that this channel is for a call to a mobile station close to the base station and so the base station is receiving a strong signal. If in this situation another call was then set up using only one slot per frame to a mobile station at the edge of the coverage area whose signal strength is close to the threshold of usability, then if that other call was allocated slot 1 or 2 of carrier 2, the base station receiver system (it may have a separate receiver for each carrier or a single receiver with a wide enough bandwidth and the appropriate demodulation

system for receiving all of the carriers) is likely to suffer from adjacent channel interference due to its own limitations or spurious transmitted power from the mobile station using channel A.

However, this problem can be completely eliminated if the call from the more distant mobile station is placed on timeslot 3 or 4 of any carrier, as the strong mobile station (channel A) is not transmitting during those slots (and the interference protection between timeslots is infinite). If slots 3 and 4 on all carriers were already being used, then the next best place to put the call from the more distant mobile would be on carrier 6 in timeslots 1 or 2, as that carrier is further away from the carrier on which the strong mobile station is transmitting (channel A). (Receiver blocking and transmitter spurious power improve rapidly further away from the carrier and an improvement of 20 dB or more might be seen six channels away.) If carrier 6 is already in use, then carrier 5 slots 1 or 2 should be tried, and so on. Only if absolutely necessary, e.g. if the system is extremely heavily loaded, should carrier 2 slots 1 or 2 be used with their enhanced likelihood of interference. In another alternative, the system could alter the existing channel allocations to allow the new channel to be assigned timeslots where it will receive less interference.

By allocating the second call from the more distant mobile station in this way, the system can reduce the likelihood of interference by carefully choosing which timeslots and carriers it allocates to a particular channel or call on the basis of the signal strength.

To further avoid and alleviate such interference it is preferred for in particular very strong signals (e.g. above a particular level) to be allocated a channel with the highest level modulation possible (and thus having the highest possible data rate) to ensure that the call takes the least time and thus causes a minimum of

interference. (This can be done because strong signals in particular will still work well at higher modulation levels).

Similar reasoning can be applied when there is a choice of allocating a call to a series of timeslots in series or parallel. For example, in Figure 12, it is better to allocate the four timeslots of the call on channel B to say, timeslot 1 on four different carriers, as not only is the call processed quicker but as the interference protection between timeslots is infinite, any allocations to timeslot 2 does not have to take the call on channel B into account. On the other hand, with the arrangement across all four timeslots shown for the call on channel B in Figure 4, care may be needed in allocating other carriers for all the four timeslots during the duration of the call using channel B.

In this preferred embodiment, power control is also used to try to reduce the effects of interference. Thus, power control can be used on the uplink to control the power of the mobile stations in the radio system more accurately at all times so that the signals received by the base station receivers are always at the same power level. The type of power control used can be selected as desired, and could, for example, be one or other or both of the known techniques referred to as open loop power control and closed loop power control. Closed loop power control is preferred, because it is the uplink signal of the base station receiver that is being both measured and controlled, whereas in open loop power control it is the downlink that is measured but the uplink that is controlled (which may lead to inaccuracies because the uplink and downlink frequencies are usually some MHz apart and thus too far apart for the amplitude fading to be correlated).

While power control can help to avoid interference fades, as discussed above, it may not allow them to be avoided in their entirety. Thus even where power

control is being used, it is still preferred to allocate timeslots and carriers to channels in accordance with the criteria discussed above, such as signal strength. However, in such a case, it may be that the actual received signal strength is not necessarily the best signal strength measurement on which to base the timeslot and carrier allocation. For example, it may be more appropriate to do the allocation on the basis of what the signal strength would be if power control was not being applied. On the other hand if that information is not fully available (as may be the case in a TETRA radio system), the allocation could be based on the signal level at call setup or on a random access channel (e.g. if power control is not used on random access signals), or on the level of power control being used or how much power control is being applied (e.g. how much power control the system is asking the mobile station to use), or on the actual received signal strength (e.g. where it is below the level of onset of power control or above its top limit or where imperfect power control such as open loop power control is being used).

A further issue with the ability of power control to remove near-far interference lies with its use in random access attempts and the call setup procedure. If power control is used during random access then that will reduce near-far interference. However, using power control for random access can result in signals from mobiles transmitting in the same slot to gain access or being at a similar strength, thereby ending up with none of them gaining access and thus extending call setup times. It may therefore be preferred not to use power control on random access channels so as to try to ensure a big enough difference in signal strength between simultaneously transmitting mobiles for one of them to gain access on the first attempt.

Random access and call setups are usually done on a

control channel and if power control is not being used for random access, then there would be a wide range of signal levels used on the control channel. It is therefore preferred in such situations to place the control channel where it is less likely to be a cause of near-far interference. This may be done by having one or more carriers used for control purposes spaced in frequency from the main contiguous group of carriers to be used for in particular multi-carrier channels. These spaced carriers may be used for all normal purposes in the communications system as well as control channel purposes, except that they are preferably not used where it is necessary to provide a multi-carrier channel. Where this is not possible, the control channel is preferably at least placed on a carrier at the edge of the group of closely spaced channels as it is then less likely to be a source of interference.

The above describes the situation in particular in relation to uplink power control. However, some radio systems also use power control on the base station transmitter, i.e. on the downlink as well as the uplink. This can create similar interference problems at the mobile receiver. (This is because when a communications system does not use power control on the downlink (as in TETRA), all the group of carriers being received by a mobile station would tend to be of similar strength as they are likely to be within the bandwidth coherence such that the reception of simultaneous data on a number of carriers is less of a problem for the mobile station. However, when downlink power control is used, the base station transmitter would turn its power down when in a call with a nearby mobile station but calls to other mobile stations at the edge of coverage on other carriers will be sent to the base station's full power and may therefore cause interference. (This situation is very similar to that described for uplink power control).) It is preferred therefore, particularly

where downlink power control is used, to also use the above criteria and considerations for the allocation of timeslots and carriers on the downlink particularly when using closely spaced or adjacent carriers.

It can be seen from the above that the assignment of timeslots and carriers on the basis of signal strength or potential signal strength (e.g. in a system where power control is used) allows the use of adjacent carriers for multi-carrier channels but with reduced near-far interference problems on the uplink. Facilitating the use of adjacent carriers also allows the use of relatively simple radio receivers instead of wide band receivers or multiple receivers to receive more than one carrier simultaneously. The use of adjacent carriers can also have a significant beneficial effect on the spectral efficiency of the communications system.

In the present embodiment, mobile stations or other parties requesting a data connection from the system give an indication of their transmission requirements in their channel or communication request.

Such an indication could, for example, be given in terms of the number of timeslots per frame. The communications system would then attempt to provide the requested number of slots in a pattern of the radio system's choice. (However, it should be noted that the communications system is not obliged to offer the number of timeslots requested, and, for example, if resources are limited it could offer a reduced number of timeslots or none at all.)

However, in the present embodiment channels of various modulation types can be used, which means that the actual data capacity of a given timeslot will depend upon the modulation type being used. For example, standard TETRA $\pi/4$ DQPSK modulation encodes two bits per modulation symbol, whereas 16-QAM encodes four bits per symbol and 64-QAM encodes six bits per symbol. Thus the

capacity of a timeslot modulated with 16-QAM is twice that of a π/4 DQPSK modulated timeslot with the same symbol rate. Similarly, the capacity of a 32-QAM timeslot would be 2.5 times that of a π/4 DQPSK timeslot using the same symbol rate, and the capacity of a 64-QAM timeslot would be three times that of a π/4 DQPSK timeslot using the same symbol rate.

Thus it is preferred that a party requesting a data communications channel requests the channel in terms of the data rate or capacity required. Such a request could be in terms of the absolute data rate required, but preferably is given in units of equivalent timeslots per frame, where an equivalent timeslot is a timeslot of a standard predetermined data capacity and is the size of a timeslot of a specified modulation type (preferably the lowest modulation level, so that timeslots can be requested in integer values). (Again, while the communications system should in the normal course try to offer the data rate or capacity requested, it is not obliged to do so.)

Thus, for example, in a TETRA system the equivalent timeslot could be the data capacity of a standard TETRA π/4 DQPSK timeslot, and where higher modulation levels such as 16-QAM, 32-QAM, etc. are available, timeslots modulated using those higher level modulation schemes will have a capacity of plural equivalent timeslots (two equivalent timeslots in the case of 16-QAM, 2.5 equivalent timeslots in the case of 32-QAM, etc.).

Thus, for example, considering the channel allocation shown in Figure 3, the user of channel a in Figure 3 could have requested a rate of six equivalent timeslots and been granted six π/4 DQPSK timeslots. A user of channel b might have requested six equivalent timeslots per frame and been granted three 16-QAM timeslots (since each 16-QAM timeslot provides two equivalent timeslots). Users of channel c might have requested fifteen equivalent timeslots per frame and

been granted six 32-QAM timeslots each of capacity 2.5 equivalent timeslots. Users of channel d might have requested fifteen equivalent timeslots per frame and been granted five 64-QAM slots each of capacity three equivalent timeslots, for example if the channel to these users was determined to be of excellent quality.

It can be seen from this that the ability to assign slots with different modulation types further enhances the flexibility of the communications channel timeslot allocation in the present embodiment, and can again help to maximise the use of bandwidth. For example in the above example, channel d can efficiently provide users with many equivalent timeslots while using a minimal number of the timeslots available per frame, thereby leaving more timeslot capacity available for other users.

In these embodiments of the present invention, it is possible for a base station of the system to modify the pattern and modulation level (or both) of the timeslots allocated to a given channel, for example if the channel quality changes or if higher priority users request channels, or the users of the channel themselves request a different number of equivalent timeslots per frame.

In the present embodiment the data to be transmitted on a given communications channel is placed into the timeslots of the channel in accordance with a predetermined ordering (numbering) scheme. This allows a receiver to reassemble the contained data in the same order as it was transmitted. While any scheme would be possible so long as both transmitter and receiver understand the same scheme, in the present embodiment the timeslots are ordered firstly by timeslot, and then by carrier number, counting from the lowest frequency carrier to the highest frequency carrier (although the reverse direction of frequency would work just as well, as would any pre-agreed ordering, as will be appreciated

by those skilled in the art). By ordering the data by timeslot first, data which is closely related is transmitted more closely in time, thereby, for example, reducing the delay time to request a re-transmission of faulty timeslots.

Thus considering the channel examples shown in Figure 3, the timeslots of channel a are ordered in the sequence:

slot 1 carrier 1
slot 1 carrier 2
slot 1 carrier 3
slot 1 carrier 4
slot 1 carrier 5
slot 1 carrier 6.

The timeslots of channel b are ordered in the sequence:

slot 2 carrier 1
slot 2 carrier 2
slot 2 carrier 3

The timeslots of channel c are ordered in the sequence:

slot 3 carrier 1
slot 3 carrier 2
slot 3 carrier 3
slot 3 carrier 4
slot 4 carrier 3
slot 4 carrier 4

and the timeslots of channel d are ordered in the order:

slot 3 carrier 6
slot 4 carrier 1
slot 4 carrier 2.

Figures 4 to 10 show examples of signalling

messages which may be used to provide the flexible channel assignments of the present embodiment and invention. The example signalling messages shown are based on an adaption of the TETRA protocol, particularly that relating to the transmission of packet data. However, the method as a whole is equally applicable to circuit mode data, and also to other communications systems, as will be appreciated by those skilled in the art.

Figure 4 shows a modified extended services broadcast information element. This element is included in the SYSINFO message broadcast by TETRA base stations. This SYSINFO message is used by mobile stations searching for a new radio base site, and the modified extended services broadcast information element of Figure 4 is used to indicate to a searching mobile station whether the radio system supports the use of higher-level modulation and multi-carrier operation. The HLM sub-element in the extended services broadcast information element of Figure 4 indicates which modulation types the base station supports. (In this regard, TC 32-QAM and TC 64-QAM referred to in Figure 4 are trellis-coded versions of 32-QAM and 64-QAM respectively (trellis coding is a particularly effective way of improving the channel coding of the data, albeit at the cost of reducing the effective bit rate per symbol).)

Figure 5 shows the contents of an exemplary modified U-LOCATION UPDATE DEMAND protocol data unit (PDU). This message can be used by a mobile station to register with the TETRA radio system. A new "extended capabilities" information element has been added to the basic PDU structure.

Figure 6 shows the contents of the "extended capabilities" information element of Figure 5. This element allows the mobile station to indicate to the radio system which higher level modulation types it

supports, and how many carriers it can receive and transmit simultaneously.

Figure 7 shows an exemplary AL-SETUP protocol data unit, which a mobile station can use to request a TETRA "advanced link". This protocol data unit could be used, for example, to request a channel for transmission of packet data. This protocol data unit includes fields whereby the mobile station can request a number of equivalent timeslots per frame, up to a maximum possible value of 60 equivalent timeslots (see Notes 9 and 11 in Figure 7). In response to such a message from a mobile station, the TETRA system would determine how it should allocate the requested equivalent timeslots in terms of numbers of carriers and the modulation level to be employed. In doing so, the radio system uses the capabilities of the mobile station declared during registration in the extended capabilities information element of the U-LOCATION UPDATE DEMAND protocol data unit as discussed above.

Figure 8 shows an exemplary MAC-RESOURCE protocol data unit. This message is used by the base station to allocate channel resources to the requesting mobile station, via a "channel allocation element" included in the message.

Figure 9 shows the contents of the channel allocation information element of the MAC-RESOURCE protocol data unit of Figure 8. This element indicates which timeslots (1 to 4, or any combination) have been allocated on the lowest (or it could equally well be the highest) allocated uplink and downlink carriers, and which modulation type is to be used on the channel.

The channel allocation information also indicates how many, if any, further carriers have been allocated to the uplink and downlink channels in the "allocation for further carrier" information element. That information element is shown in more detail in Figure 10. It is repeated for each additional carrier and

gives the uplink and downlink timeslot allocation for each additional carrier. Asymmetric uplink and downlink carrier and modulation, etc., allocations are possible.

It can be seen from the above that these various messages and information elements described give a means of providing a completely flexible allocation of timeslots to channels, in accordance with the present invention.

Thus it can be seen from the above that the present invention provides a method of allocating timeslots in a multi-carrier communication channel, in which a channel can be made up of any number or combination of timeslots of equal data capacity. The allocated timeslot pattern repeats in frames but otherwise can be arranged as desired. This allows greater flexibility in adding and removing channels of varying sizes. It is particularly useful for high-speed data communication where multiple radio carriers may be combined to provide the required data rate.

CLAIMS

1. A method of operating a time division multiple access communications system in which plural individual carrier frequencies are divided into regularly repeating frames each comprising a predetermined number of timeslots, the method comprising:

allocating for use as a communications channel a pattern of timeslots on more than one carrier frequency in a single transmission frame which repeats for selected succeeding transmission frames.

2. The method of claim 1, wherein the timeslot pattern repeats for each successive transmission frame until the channel is no longer needed.

3. The method of claim 1 or 2, comprising allocating the timeslots on a carrier frequency of the channel such that adjacent timeslots on the carrier are at regularly spaced intervals.

4. A method of operating a time division multiple access communications system in which plural individual carriers are divided into regularly repeating frames each comprising a predetermined number of timeslots, the method comprising:

allocating for use as a communications channel a pattern of timeslots on more than one carrier frequency in a single transmission frame which repeats for selected succeeding transmission frames, and in which pattern adjacent timeslots on a carrier frequency of the channel are at regular intervals.

5. The method of any one of the preceding claims, further comprising selecting the modulation scheme to use for the multi-carrier channel.

6. The method of any one of the preceding claims, further comprising selecting the interleaving scheme to be used for the multi-carrier channel.

7. The method of any one of the preceding claims, further comprising, where interleaving is to be used for the multi-carrier channel, interleaving the data on each carrier frequency of the channel separately to the data on the other carrier frequencies of the channel.

8. The method of any one of the preceding claims, further comprising changing the carrier frequencies, timeslot pattern, and/or modulation scheme allocated to a communications channel while the channel is in use.

9. The method of any one of the preceding claims, further comprising assigning plural simultaneous multi-carrier channels each having a pattern of timeslots on more than one carrier frequency in a single transmission frame which repeats for selected succeeding transmission frames.

10. The method of any one of the preceding claims, further comprising reserving a selected pool of carrier frequencies for multi-carrier channel use.

11. The method of claim 10, wherein the pool of carrier frequencies reserved for use for the multi-carrier channels comprises a contiguous block of adjacent carrier frequencies.

12. The method of claim 10 or 11, further comprising varying the number of carrier frequencies in the pool according to the current usage of the communications system.

13. The method of any one of the preceding claims,

further comprising assigning a carrier frequency simultaneously to both a multi-carrier channel and another channel.

14. The method of any one of the preceding claims, further comprising allocating a contiguous block of adjacent carrier frequencies to the multi-carrier channel.

15. The method of any one of the preceding claims, wherein the timeslot allocation is based on a signal strength indication for another signal in the system.

16. A method of allocating timeslots and carrier frequencies to a communications channel in a communications system in which channels comprising multiple carriers are possible, comprising:

allocating timeslots and/or carriers to the channel on the basis of an indication of the signal strength of a signal that is to use the channel and/or on the basis of an indication of the signal strength of a signal that is using an existing channel of the communications system.

17. The method of claim 15 or 16, comprising determining timeslots that already contain a signal having greater than a particular indicated signal strength, and preferentially allocating a new channel timeslots that are not simultaneous with timeslots that already contain a signal having greater than the particular indicated signal strength.

18. The method of claim 15, 16 or 17, further comprising determining timeslots that already contain a signal having greater than a particular indicated signal strength, and allocating a new channel on carrier frequencies that are spaced as far in frequency as

possible given the available frequency range and available carrier frequencies within the range from timeslots that already contain a signal having greater than the particular indicated signal strength.

19. The method of any one of the preceding claims, further comprising determining whether the signal a channel is to carry for a call will have a signal strength greater than a particular level, and if it will, allocating the timeslots in the channel for the call in such a way as to minimise as far as possible the number of timeslots and/or the time taken to complete the call.

20. The method of any one of the preceding claims, further comprising determining whether the signal a channel is to carry for a call will have a signal strength greater than a particular level, and if it will, allocating the timeslots in the channel for the call in such a way to maximise as far as possible the number of simultaneous timeslots used for the channel for the call.

21. The method of any one of the preceding claims, further comprising altering existing channel timeslot allocations to enable a new channel to be allocated timeslots.

22. The method of any one of the preceding claims, further comprising a communications station of the system requesting a communications channel and including in the request information about the type of channel desired.

23. The method of claim 22, wherein the channel request includes an indication of the data rate or capacity desired for the communications channel.

24. The method of claim 23, wherein the data rate or capacity indication comprises an indication of a number of standard data capacity timeslots desired for the channel.

25. A method of operating a communications system in which communications channels comprised of plural different carrier frequencies can be used, the method comprising:

a station of the communications system transmitting a request for a communications channel, and including in its request an indication of the data transmission rate or capacity required for the communications channel; and

the system in response to such a request allocating a communications channel comprised of timeslots on plural different carriers, wherein the timeslots allocated to the channel are based on the indicated data transmission rate or capacity.

26. The method of any one of the preceding claims, further comprising placing the data to be transmitted in the communications channel in the timeslots of the channel according to a predetermined ordering scheme.

27. A method of transmitting data on a communications channel which uses timeslots on plural carrier frequencies, comprising:

allocating the data to the timeslots of the channel for transmission in accordance with a predetermined ordering scheme.

28. The method of any one of the preceding claims, further comprising placing the data to be transmitted in the communications channel in the timeslots of the channel such that the timeslots of the channel are filled up in order of their positions in time.

29. The method of claim 28, wherein simultaneous timeslots are filled in order of carrier number.

30. A method of operating a time division multiple access communications system in which plural individual carrier frequencies are divided into regularly repeating frames each comprising a predetermined number of timeslots, the method comprising:

allocating for use as an uplink communications channel a pattern of timeslots on more than one carrier frequency in a single transmission frame which repeats for selected succeeding transmission frames; and

allocating for use as an downlink communications channel a pattern of timeslots on more than one carrier frequency in a single transmission frame which repeats for selected succeeding transmission frames.

31. The method of claim 30, further comprising allocating asymmetric communications channels for an associated uplink and downlink channel pair.

32. A method of operating a communications system, comprising allocating an associated uplink and downlink communications channel pair to users of the system, wherein the timeslot pattern allocated to the uplink channel is different to the timeslot pattern allocated to the downlink channel.

33. A method of interleaving data to be transmitted on a communications channel comprising plural different carrier frequencies, the method comprising:

interleaving the data on each carrier frequency of the channel separately to the data on the other carrier frequencies of the channel.

34. A method of allocating radio frequency carriers in a communications system to a communications channel that

uses plural radio frequency carriers, the method comprising:

allocating as far as possible adjacent frequency carriers to the channel.

35. An apparatus for use in a time division multiple access communications system in which plural individual carrier frequencies are divided into regularly repeating frames each containing the same number of timeslots, the apparatus comprising:

means for allocating for use as a communications channel a pattern of timeslots on more than one carrier frequency in a single transmission frame which will repeat for selected succeeding transmission frames.

36. An apparatus for use in a time division multiple access communications system in which plural individual carriers are divided into regularly repeating frames each containing the same number of timeslots, the apparatus comprising:

means for allocating for use as a communications channel a pattern of timeslots on more than one carrier frequency in a single transmission frame which repeats for selected succeeding transmission frames and in which adjacent timeslots on a carrier frequency of the channel are at regular intervals.

37. The apparatus of claim 35 or 36, wherein the communications system supports plural different modulation schemes, and further comprising means for selecting the modulation scheme to be used for the multi-carrier channel.

38. The apparatus of claim 35, 36 or 37, further comprising means for selecting the interleaving scheme to be used for the multi-carrier channel.

39. The apparatus of any one of claims 35 to 38, further comprising means for interleaving data on the multi-carrier channel comprising means for interleaving the data on each carrier frequency of the channel separately to the data on the other carrier frequencies of the channel.

40. The apparatus of any one of claims 35 to 39, further comprising means for changing the carrier frequencies, timeslot pattern, and/or modulation scheme allocated to a communications channel while the channel is in use.

41. The apparatus of any one of claims 35 to 40, further comprising means for reserving a selected pool of carriers for multi-carrier channel use.

42. The apparatus of claim 41, wherein the pool of carriers reserved for use for the multi-carrier channels comprises a contiguous block of adjacent carriers.

43. The apparatus of any one of claims 35 to 42, further comprising means for determining a signal strength indication for a signal in the system, and wherein the timeslot allocation means comprises means for allocating timeslots to a channel based on the determined signal strength indication.

44. An apparatus for allocating timeslots and carrier frequencies to a communications channel in a communications system in which channels comprising multiple carriers are possible, comprising:

means for allocating timeslots and/or carriers to the channel on the basis of an indication of the signal strength of a signal that is to use the channel and/or on the basis of an indication of the signal strength of a signal that is using an existing channel of the

communications system.

45. The apparatus of claim 43 or 44, comprising means for determining timeslots that already contain a signal having greater than a particular indicated signal strength and means for preferentially allocating a new channel timeslots that are not simultaneous with the timeslots that already contain a signal having greater than the particular indicated signal strength.

46. The apparatus of claim 43, 44 or 45, comprising means for determining timeslots that already contain a signal having greater than a particular indicated signal strength, and means for allocating a new channel on carrier frequencies that are spaced as far in frequency as possible given the available frequency range and available carrier frequencies within the range from timeslots that already contain a signal having greater than the particular indicated signal strength.

47. The apparatus of any one of claims 35 to 46, further comprising means for determining whether the signal a channel is to carry for a call will have a signal strength greater than a particular level, and means for, if it will, allocating the timeslots in the channel for the call in such a way as to minimise as far as possible the number of timeslots and/or the time taken to complete the call.

48. The apparatus of any one of claims 35 to 47, further comprising means for determining whether the signal a channel is to carry for a call will have a signal strength greater than a particular level, and means for, if it will, allocating the timeslots in the channel for the call in such a way to maximise as far as possible the number of simultaneous timeslots used for the channel for the call.

49. The apparatus of any one of claims 35 to 48, further comprising means for placing the data to be transmitted in the communications channel in the timeslots of the channel according to a predetermined ordering scheme.

50. An apparatus for transmitting data on a communications channel which uses timeslots on plural carrier frequencies, comprising:

means for allocating the data to the timeslots of the channel for transmission in accordance with a predetermined ordering scheme.

51. The apparatus of any one of claims 35 to 50, further comprising means for placing the data to be transmitted in the communications channel in the timeslots of the channel such that the timeslots of the channel are filled up in order of their positions in time.

52. The apparatus of claim 51, further comprising means for filling simultaneous timeslots in order of carrier number.

53. A communications system in which communications channels comprised of plural different carrier frequencies can be used, the system comprising:

a communications station comprising means for transmitting a request for a communications channel, and including in its request an indication of the data transmission rate or capacity required for the communications channel; and

the system further comprising means for, in response to such a request, allocating a communications channel comprised of timeslots on plural different carriers, wherein the timeslots allocated to the channel are based on the indicated data transmission rate or

capacity.

54. A communications station of a communications system in which communications channels comprised of plural different carrier frequencies can be used, the communications station comprising:

means for transmitting a request for a communications channel, and including in its request an indication of the data transmission rate required for the communications channel.

55. A communications station of a communications system in which communications channels comprised of plural different carrier frequencies can be used, the communications station comprising:

means for receiving a request for a communications channel which includes an indication of the data transmission rate required for the communications channel; and

means for, in response to such a request, allocating a communications channel comprised of timeslots on plural different carriers, wherein the timeslots allocated to the channel are based on the indicated data transmission rate or capacity.

56. An apparatus for interleaving data to be transmitted on a communications channel comprising plural different carrier frequencies, the apparatus comprising:

means for interleaving the data on each carrier frequency of the channel separately to the data on the other carrier frequencies of the channel.

57. An apparatus for allocating radio frequency carriers in a communications system to a communications channel that uses plural radio frequency carriers, the apparatus comprising:

means for allocating as far as possible adjacent frequency carriers to the channel.

58. A communications system in which multiple-carrier frequency channels can be provided, wherein the carrier frequencies available for use in multi-carrier channels comprise a contiguous block of adjacent carrier frequencies.

59. A TETRA mobile communications system comprising the features of any one of claims 35 to 58.

60. A computer program element comprising computer software code portions for performing the method of any one of claims 1 to 34 when the program element is run on data processing means.

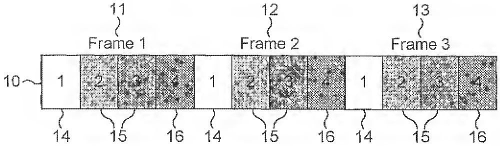
11
Frame 1
12
Frame 2
13
Frame 3
10
1
2
3
4
1
2
3
4
1
2
3
4
14
15
16
14
15
16
14
15
16

FIG. 1

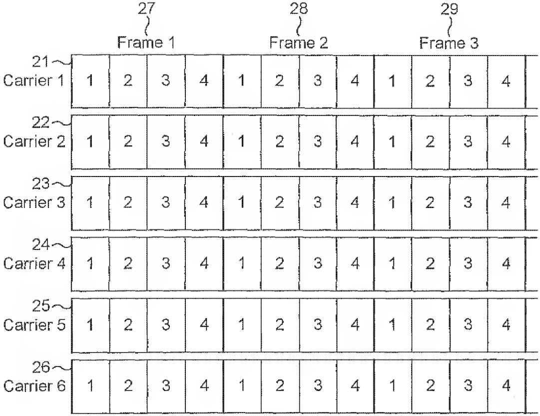
27
Frame 1
28
Frame 2
29
Frame 3
21
Carrier 1
22
Carrier 2
23
Carrier 3
24
Carrier 4
25
Carrier 5
26
Carrier 6
1 2 3 4 1 2 3 4 1 2 3 4

FIG. 2

	Slot 1	Slot 2	Slot 3	Slot 4
Carrier 1	a	b	c	d
Carrier 2	a	b	c	d
Carrier 3	a	b	c	c
Carrier 4	a		c	c
Carrier 5	a	d		
Carrier 6	a	d	d	

FIG. 3

Information element	Length	M/C/O	Value	Remark
Security information	8			Refer to EN 300 392-7.
SDS-TL addressing Method	2	M	00_2	Reserved
			01_2	Service centre addressing preferred (note)
			10_2	Never use service centre addressing (note)
			11_2	MS choice to use service centre addressing (note)
HLM	2	M	00_2	HLM not supported on this cell
			01_2	π/4-DQPSK and 16-QAM modulation supported on this cell
			10_2	π/4-DQPSK, 16-QAM and TC 32-QAM modulation supported on this cell
			11_2	π/4-DQPSK, 16-QAM, TC 32-QAM and TC 64-QAM modulation supported on this cell
MC	1	M	0	MC not supported on this cell
			1	MC supported on this cell
Reserved	7	M		Reserved, value shall be set to "0000000_2"

Extended service broadcast information element

FIG. 4

Information element	Length	Type	C/O/M	Remark
PDU type	4	1	M	
Location update type	3	1	M	
Request to append LA	1	1	M	
Cipher control	1	1	M	
Ciphering parameters	10		C	Note
Class of MS	24	2	O	
Energy saving mode	3	2	O	
LA information		2	O	
SSI	24	2	O	ISSI of the MS
Address extension	24	2	O	MNI of the MS
Group identity location demand		3	O	
Group report response		3	O	
Authentication uplink		3	O	See EN 300 392-7
Extended capabilities		3	O	
Proprietary		3	O	
NOTE: Information element "Ciphering parameters" is not present if "Cipher control" is set to "0", "ciphering off". Information element "ciphering parameters" is present if "Cipher control" is set to "1", "ciphering on".				

U-LOCATION UPDATE DEMAND contents

FIG. 5

Information sub-element	Length	Type	C/O/M	Value	Remark
HLM mode	2	1	M	00_2	HLM not supported
				01_2	π/4-DQPSK and 16-QAM supported
				10_2	π/4-DQPSK, 16-QAM and TC 32-QAM supported
				11_2	π/4-DQPSK, 16-QAM, TC 32-QAM and TC 64-QAM supported
Number of TEDS carriers on which the MS can transmit simultaneously	4	1	M	0000_2	1 simultaneous transmit carrier
				0001_2	2 simultaneous transmit carriers
				...etc.	...etc.
				0101_2	6 simultaneous transmit carriers
				0110_2	Reserved
				...etc.	...etc.
				1111_2	Reserved
Number of TEDS carriers which the MS can receive simultaneously	4	1	M	0000_2	1 simultaneous receive carrier
				0001_2	2 simultaneous receive carriers
				...etc.	...etc.
				0101_2	6 simultaneous receive carriers
				0110_2	Reserved
				...etc.	...etc.
				1111_2	Reserved
Capability to receive signal with downlink transmit diversity	2	1	M	00_2	Off
				01_2	Off or 2-branch
				10_2	Reserved
				11_2	Reserved
Reserved	tbd		M	0	Default value = 0

Extended capabilities information element contents

FIG. 6

Information element	Length	Type	Value	Remark
LLC PDU type	4	M	see table 304	
Advanced link service	1	M	0	Unacknowledged service
			1	Acknowledged service
Advanced link number N.261	2	M	00_2	Advanced link number 1
			01_2	Advanced link number 2
			10_2	Advanced link number 3
			11_2	Advanced link number 4
Maximum length of a TL-SDU N.271	3	M	000_2	32 octets
			001_2	64 octets
			010_2	128 octets
			011_2	256 octets
			100_2	512 octets
			101_2	1 024 octets
			110_2	2 048 octets
			111_2	4 096 octets
Connection width	1	M	0	Single slot connection
			1	Multislot connection
Advanced link symmetry	1	M	0	Symmetric advanced link
			1	Asymmetric advanced link
Number of timeslots (M_1) used per TDMA frame on uplink or on uplink and downlink N.264 (note 1)	2	C	00_2	1 timeslot
			01_2	2 timeslots
			10_2	3 timeslots
			11_2	4 timeslots
Number of timeslots (M_2) used per TDMA frame on downlink N.264 (note 2)	2	C	00_2	1 timeslot
			01_2	2 timeslots
			10_2	3 timeslots
			11_2	4 timeslots
Data transfer throughput (mean value) (note 3)	3	M	000_2	Network dependent minimum
			001_2	1/32 of maximum
			010_2	1/16 of maximum
			011_2	1/8 of maximum
			100_2	1/4 of maximum
			101_2	1/2 of maximum
			110_2	Reserved
			111_2	Maximum
TL-SDU window size N.272 or N.281 (note 4)	2	M	00_2	Reserved
			01_2	SDU window size = 1
			10_2	SDU window size = 2
			11_2	SDU window size = 3
Maximum number of TL-SDU re-transmissions N.273 or TL-SDU repetition N.282 (note 5)	3	M	000_2	no re-transmissions
			001_2	1 re-transmission
			...etc.	...etc.
			111_2	7 re-transmissions,
Maximum number of segment re-transmissions N.274	4	M	0000_2	no re-transmissions
			0001_2	1 re-transmission
			...etc.	...etc.
			1111_2	15 re-transmissions
Set-up report	3	M	000_2	Success
			001_2	Service definition
			010_2	Service change
			011_2	Reset
			100_2	Reserved
			101_2	Reserved
			110_2	Reserved
			111_2	TEDS

AL-SETUP PDU contents

FIG. 7

Information element	Length	Type	Value	Remark
N(S) (note 6)	8	C		Sent TL-SDU number
TEDS set-up report (note 7)	3	C	000_2	Success
			001_2	Service definition
			010_2	Service change
			011_2	Reset
			100_2	Reserved
			101_2	Reserved
			110_2	Reserved
			111_2	Reserved
Extension (E_1) of number of timeslots used per TDMA frame on uplink or on uplink and downlink (notes 8 and 9).	6	C	000000_2	$E_1 = 0$
			000001_2	$E_1 = 1$
			...etc.	...etc.
			001110_2	$E_1 = 14$
			001111_2	Reserved
			...etc.	...etc.
			111111_2	Reserved
Extension (E_2) of number of timeslots used per TDMA frame on downlink (notes 10 and 11)	6	C	000000_2	$E_2 = 0$
			000001_2	$E_2 = 1$
			...etc.	...etc.
			001110_2	$E_2 = 14$
			001111_2	Reserved
			...etc.	...etc.
			111111_2	Reserved

NOTE 1: This element shall be present only for the multislot connection (i.e. Connection width element set to "1"). In case of symmetric advanced link this element defines the number of timeslots used per TDMA frame both in uplink and downlink.

NOTE 2: This element shall be present only for the multislot connection and asymmetric advanced link (i.e. Connection width element set to "1" and Advanced link symmetry element set to "1"). The usage of asymmetric advanced link is outside the scope of the present document.

NOTE 3: The BS may use a control channel as a general packet data channel, supporting advanced links for many MSs, where each MS may be offering/receiving data packets at a low rate or intermittently. This parameter gives the BS the necessary information for planning its resource allocations.

NOTE 4: TL-SDU window sizes N.272 and N.281 are for the acknowledged and unacknowledged services respectively.

NOTE 5: For the acknowledged service the N.273 defines how many times the TL-SDU may be re-transmitted and for the unacknowledged (point-to-multipoint) service, N.282 means the number of times the TL-SDU will be repeated by the sender.

NOTE 6: This element shall be present only for the unacknowledged service (i.e. advanced link service element set to "0").

NOTE 7: This element shall be present only for a TEDS connection (i.e. set-up report element set to 111_2).

NOTE 8: This element shall be present only for a TEDS connection (i.e. set-up report element set to 111_2). In case of symmetric advanced link this element (together with M_1) defines the number of equivalent timeslots used per TDMA frame both in uplink and downlink.

NOTE 9: Total number of equivalent timeslots used per TDMA frame = $(4 \times E_1) + M_1$

NOTE 10: This element shall be present only for a TEDS connection with an asymmetric advanced link (i.e. set-up report element set to 111_2 and Advanced link symmetry element set to "1").

NOTE 11: Total number of equivalent timeslots used per TDMA frame = $(4 \times E_2) + M_2$

FIG. 7 CONTD

Information element	Length	Type	Value	Remark
PDU type	2	M	00_2	MAC-RESOURCE
Fill bit indication	1	M	0	No fill bits present
			1	Fill bit(s) present
Position of grant	1	M	0	Slot grant (if any) is on current channel
			1	Slot grant (if any) is on allocated channel
Encryption mode	2	M	00_2	Not encrypted
			01_2	See ETS 300 392-7 [13]
			10_2	See ETS 300 392-7 [13]
			11_2	See ETS 300 392-7 [13]
Random access flag	1	M	0	Undefined
			1	Random Access Acknowledged
Length indication	6	M	000000_2	Reserved
			000001_2	Reserved
			000010_2	Length for null PDU
			000011_2	Reserved
			000100_2	Length of MAC PDU in units of y octets (note)
			...etc.	...etc.
			100010_2	Longest MAC PDU
			100011_2	Reserved
			...etc.	...etc.
			111101_2	Reserved
			111110_2	Second half slot stolen in STCH
			111111_2	Start of fragmentation
Address type	3	M	000_2	Null PDU
			001_2	SSI
			010_2	Event Label
			011_2	USSI (migrating MS un-exchanged address)
			100_2	SMI (management address)
			101_2	SSI + Event Label (event label assignment)
			110_2	SSI + Usage Marker (usage marker assignment)
			111_2	SMI + Event Label (event label assignment)
Address	34/ 30/ 24/ 10	M		SSI/SMI + Event Label SSI + Usage Marker SSI, USSI or SMI Event Label
Power control flag	1	M	0	No power control element in PDU
			1	Power control element in PDU
Power control element	4	C		see power control element definition
Slot granting flag	1	M	0	No slot granting elements in PDU
			1	Slot granting element in PDU
Slot granting element	8	C		see slot granting element definition
Channel allocation flag	1	M	0	No channel allocation element in PDU
			1	Channel allocation element in PDU
Channel allocation element	variable	C		see channel allocation element definition
TM-SDU	variable	C		
NOTE: y = 1 when the MAC-RESOURCE PDU is sent using $\pi/4$ DQPSK. y = 2 when the MAC-RESOURCE PDU is sent using 16-QAM y = 2 when the MAC-RESOURCE PDU is sent using TC 32-QAM y = 3 when the MAC-RESOURCE PDU is sent using TC 64-QAM				

MAC-RESOURCE PDU contents

FIG. 8

Information element	Length	Type	Value	Remark
Allocation type	2	M	00_2	Replace current channel with specified channel
			01_2	Additional channel allocation
			10_2	Quit current channel and go to specified channel
			11_2	Replace current channel with specified channel plus carrier specific signalling channel in slot 1
Timeslot assigned for lowest allocated carrier (note 1)	4	M	0000_2	Go to appropriate common control channel (MCCH or common SCCH)
			0001_2	Timeslot number 4
			0010_2	Timeslot number bit map
			...etc.	...etc.
			1110_2	Timeslot number bit map
			1111_2	All 4 timeslots
Up/downlink assigned	2	M	00_2	Enhanced channel allocation e.g. allocation of TEDS channel
			01_2	Downlink only
			10_2	Uplink only
			11_2	Both uplink and downlink
CLCH permission for lowest allocated carrier (note 1)	1	M	0	No immediate CLCH permission
			1	Immediate CLCH permission
Cell change flag	1	M	0	No cell change
			1	Cell change
Carrier number for lowest allocated carrier (note 1)	12	M		Carrier frequency number
Extended carrier numbering flag	1	M	0	No extended carrier numbering
			1	Extended carrier numbering
Frequency band (note 2)	4	C		Provision for different frequency bands
Offset (note 2)	2	C		Provision for different offsets
Duplex spacing (note 2)	3	C		Provision for different duplex spacing
Reverse operation (note 2)	1	C	0	Normal
			1	Reverse
Monitoring pattern (see clause 9)	2	M	00_2	No monitoring pattern
			01_2	One monitoring pattern
			10_2	Two monitoring patterns
			11_2	Three monitoring patterns
Frame 18 monitoring pattern (note 3)	2	C	00_2	No monitoring pattern
			01_2	One monitoring pattern
			10_2	Two monitoring patterns
			11_2	Three monitoring patterns
Downlink modulation type (note 4)	2	C	00_2	π/4-DQPSK
			01_2	16-QAM
			10_2	TC 32-QAM
			11_2	TC 64-QAM
Uplink modulation type (note 4)	2	C	00_2	π/4-DQPSK
			01_2	D8PSK
			10_2	TC 32-QAM
			11_2	TC 64-QAM
Downlink transmit diversity (note 4)	2	C	00_2	Off
			01_2	2-branch
			10_2	Reserved
			11_2	Reserved
Up/downlink assigned for enhanced channel allocation (note 4)	2	C	00_2	Reserved
			01_2	Downlink only
			10_2	Uplink only
			11_2	Both uplink and downlink

Channel allocation information element contents

FIG. 9

Information element	Length	Type	Value	Remark
Uplink usage of lowest allocated carrier (note 4)	1	C	0	Uplink not used
			1	Uplink used
Number of further carriers (note 4)	4	C	0000_2	No further carriers
			0001_2	One further carrier
			...etc.	...etc.
			0101_2	Five further carriers
			0110_2	Reserved
			...etc.	...etc.
			1111_2	Reserved
Allocation for further carrier (notes 4 and 5)		C		See note 5
Reserved (note 4)	tbd	C		Default value = all zeros

NOTE 1: For TETRA1 only one carrier is assigned with a channel allocation element, so the "lowest allocated carrier" is the only allocated carrier.
NOTE 2: This element shall be present only in the case of extended carrier numbering i.e. "extended carrier numbering flag" set to 1.
NOTE 3: This element shall be present only in the case that no monitoring pattern is assigned i.e. "monitoring pattern" element set to 00_2.
NOTE 4: This element shall be present only for an enhanced channel allocation i.e. "up/downlink assigned" element set to 00_2.
NOTE 5: This element shall be repeated for each further carrier as indicated by the "number of further carriers" element. Each "allocation for further carrier" element comprises a set of sub-elements.

FIG. 9 CONT'D

Information element	**Length**	**Type**	**Value**	**Remark**
Relative carrier number	4	M	0000_2	Reserved
			0001_2	Carrier number = Carrier number for lowest allocated carrier + 1
			...etc.	...etc.
			0101_2	Carrier number = Carrier number for lowest allocated carrier + 5
			0110_2	Reserved
			...etc.	...etc.
			1111_2	Reserved
Timeslot assigned	4	M	0000_2	Reserved
			0001_2	Timeslot number 4
			0010_2	Timeslot number bit map
			...etc.	...etc.
			1110_2	Timeslot number bit map
			1111_2	All 4 timeslots
			01_2	Downlink only
			10_2	Uplink only
			11_2	Both uplink and downlink
Uplink usage	1	M	0	Uplink not used
			1	Uplink used
CLCH permission	1	M	0	No immediate CLCH permission
			1	Immediate CLCH permission
Reserved	tbd	M		Default value = all zeros

Allocation for further carrier information element contents

FIG. 10

	Slot 1	Slot 2	Slot 3	Slot 4
Carrier 1	A	A		
Carrier 2				
Carrier 3				
Carrier 4				
Carrier 5				
Carrier 6				

FIG. 11

	Slot 1	Slot 2	Slot 3	Slot 4
Carrier 1	B	B	B	B
Carrier 2				
Carrier 3				
Carrier 4				
Carrier 5				
Carrier 6				

FIG. 12

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
9 January 2003 (09.01.2003)

PCT

(10) International Publication Number
WO 03/003617 A3

(51) International Patent Classification⁷: H04B 7/26, H04J 4/00

(21) International Application Number: PCT/GB02/03009

(22) International Filing Date: 28 June 2002 (28.06.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0116015.9 29 June 2001 (29.06.2001) GB

(71) Applicant *(for all designated States except US)*: **SEPURA LIMITED** [GB/GB]; Radio House, St. Andrews Road, Cambridge CB4 1GR (GB).

(72) **Inventors; and**
(75) **Inventors/Applicants** *(for US only)*: **BALL, Diana, Margaret** [GB/GB]; 56 Barrons Way, Comberton, Cambridgeshire CB3 7DR (GB). **RAYNE, Mark, Wentworth** [GB/GB]; 5 St. James Close, Stretham, Nr. Ely, Cambridgeshire CB6 2 ND (GB). **WILSON, John, Francis** [GB/GB]; Westcroft Cottage, 206 High Green, Great Shelford, Cambridge CB2 5EG (GB).

(74) **Agent: FRANK B, DEHN & CO.**; 179 Queen Victoria Street, London EC4V 4EL (GB).

(81) **Designated States** *(national)*: AE, AG, AL, AM (utility model), AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ (utility model), DE (utility model), DK (utility model), DM, DZ, EC, EE (utility model), ES, FI (utility model), GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK (utility model), SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) **Designated States** *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declaration under Rule 4.17:
as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for all designations

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

(88) **Date of publication of the international search report:** 12 June 2003

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

WO 03/003617 A3

(54) **Title:** COMMUNICATIONS SYSTEMS

	Slot 1	Slot 2	Slot 3	Slot 4
Carrier 1	a	b	c	d
Carrier 2	a	b	c	d
Carrier 3	a	b	c	c
Carrier 4	a		c	c
Carrier 5	a	d		
Carrier 6	a	d	d	

(57) **Abstract:** A communications system in which communications stations can transmit and receive more than one carrier frequency simultaneously. Communications channels consisting of simultaneous timeslots on different carrier frequencies are assigned to parties requesting a call depending on the particular data rate requested for the call. The system determines how many timeslots per frame the requested data rate corresponds to and then allocates the appropriate number of timeslots to the channel. Although an integer number of timeslots per frame must be allocated to the channel, the slots may otherwise be allocated in any way desired. Thus, for example, a data rate corresponding to six timeslots per frame could be provided by a channel (channel a) which consists of one slot on each of six different carriers or by a more dispersed allocation of slot 3 on carriers 1 to 4 and slot 4 on carriers 3 and 4 (channel c). A rate of three slots per frame could be provided by a channel (channel b) consisting of slot 2 on carriers 1, 2 and 3. These slot patterns repeat for successive frames.

INTERNATIONAL SEARCH REPORT	Inte[redacted]onal Application No PCT/GB 02/03009

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B7/26 H04J4/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 680 168 A (AT & T CORP) 2 November 1995 (1995-11-02) abstract; figures 5,6 column 3, line 21 - line 45 column 4, line 41 -column 7, line 58 ---	1-15, 21-31, 35-43, 49-55, 59,60
X	EP 0 841 763 A (NOKIA MOBILE PHONES LTD) 13 May 1998 (1998-05-13) abstract; figures 2A,3 column 5, line 9 - line 36 column 6, line 38 -column 8, line 5 column 8, line 39 -column 10, line 57 ---	1-15, 21-31, 35-43, 49-55, 59,60
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 September 2002	05. [illegible]
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	**Authorized officer** Staeger, R

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 198 45 057 A (SIEMENS AG) 6 April 2000 (2000-04-06) abstract; figure 1 column 1, line 54 -column 2, line 51 column 3, line 67 -column 5, line 32; claim 1 ---	1,4,25, 27,30, 35,36, 50,53,55
X	US 5 134 615 A (GEHARDT WILLY ET AL) 28 July 1992 (1992-07-28) abstract; figure 2 column 2, line 11 - line 62 ---	1,4,25, 27,30, 35,36, 50,53,55
X	OJANPERÄ ET AL: "FRAMES-hybrid multiple access technology" IEEE ISSSTA. IEEE INTERNATIONAL SYMPOSIUM ON SPREAD SPECTRUM TECHNIQUES AND APPLICATIONS, XX, XX, no. 1, 22 September 1996 (1996-09-22), pages 320-324, XP002077020 paragraph [00IV]; figure 1 ---	1,4,25, 27,30, 35,36, 50,53,55
P,X	WO 02 15435 A (DENT PAUL W ;ERICSSON INC (US)) 21 February 2002 (2002-02-21) abstract; figures 1,2 page 6, line 11 -page 8, line 33 ---	1,4,25, 27,30, 35,36, 50,53,55
X	US 6 038 221 A (WICKMAN JOHAN ET AL) 14 March 2000 (2000-03-14) figures 2-4 -----	32

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB 02/03009

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-15, 21-31, 32, 35-43, 49-55, 59, 60

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-15,21-31,32,35-43,49-55,59,60

   1.1. Claims: 1-15,21-31,35-43,49-55,59,60
   A method, apparatus and system in which plural individual carrier frequencies are divided into regularly repeating frames each comprising a predetermined number of timeslots, wherein for use as a communication channel there is allocated a pattern of timeslots on more than one carrier frequency in a single transmission frame.

   1.2. Claim : 32
   A method of operating and allocating an associated uplink and downlink communications channel pair to users of a communication system, wherein the time slot pattern allocated to the uplink channel is different to the timeslot pattern allocated to the downlink channel.

2. Claims: 16-20, 44-48

   A method and apparatus of allocating timeslots and/or carriers to a channel on the basis of an indication of the signal of a signal that is to use the channel and /or on the basis of the signal strength of a signal using an existing channel.

3. Claims: 33, 56

   A method and apparatus of interleaving data to be transmitted on a communications channel comprising plural different carrier frequencies.

4. Claims: 34, 57, 58

   Method, apparatus and system of allocating radio frequency carriers to a communication channel that uses plural radio frequency carriers, wherein as far as possible adjacent frequency carriers are allocated to the channel.

Please note that all inventions mentioned under item 1, although not necessarily linked by a common inventive concept, could be searched without effort justifying an additional fee.

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
EP 0680168	A	02-11-1995	US	6018528 A	25-01-2000
			CA	2145700 A1	29-10-1995
			EP	0680168 A2	02-11-1995
			JP	7303090 A	14-11-1995
			US	6064662 A	16-05-2000
EP 0841763	A	13-05-1998	FI	964308 A	26-04-1998
			BR	9705138 A	18-05-1999
			EP	0841763 A1	13-05-1998
			JP	10190621 A	21-07-1998
			US	6031827 A	29-02-2000
DE 19845057	A	06-04-2000	DE	19845057 A1	06-04-2000
			WO	0019640 A1	06-04-2000
US 5134615	A	28-07-1992	AU	644024 B2	02-12-1993
			AU	8747491 A	28-04-1992
			BR	9105907 A	13-10-1992
			CA	2068430 A1	06-04-1992
			EP	0504377 A1	23-09-1992
			JP	2729332 B2	18-03-1998
			JP	5503404 T	03-06-1993
			MX	9101459 A1	05-06-1992
			WO	9206546 A1	16-04-1992
WO 0215435	A	21-02-2002	AU	8056901 A	25-02-2002
			WO	0215435 A1	21-02-2002
US 6038221	A	14-03-2000	SE	504721 C2	14-04-1997
			AU	3357495 A	22-03-1996
			EP	0776582 A2	04-06-1997
			SE	9402764 A	20-02-1996
			WO	9607278 A2	07-03-1996